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Shorter period Laser Induced Periodic Surface Structure generation with a Multi-Plane Light Conversion Beam Shaper and a femtosecond laser at 515nm.

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Abstract

Processing at 515nm presents advantages compared to 1030nm: the depth of field is four times longer and the achievable sharpness is twice smaller. Moreover, it has been demonstrated that processing at 515nm is more efficient in terms of ablation efficiency for some materials despite the 50% conversion loss in terms of energy.
We describe how a beam shaper based on Multi-Plane Light Conversion (MPLC) combined with a 300fs 515nm laser improves Laser Induced Periodic Surface Structure (LIPSS) generation on stainless steel. The beam-shaper provides a sharper square top-hat with an extended depth of field up to 10 times higher compared to other beam-shaping technologies.
LIPSS has been generated with 130µm and 50µm squares enabling a smaller period compared to IR processing, down to 0,5µm. The transition from the textured to non-textured area is reduced to 2µm thanks to the sharp edges of the top-hat profile.

Keywords: Laser ; LIPSS ; ultra-short pulses ; green laser ; laser induced periodic surface ; surface texturation ; dynamic tailored beam shaping; transtion

1. Surface structuring

Surface structuring is used for a variety of applications, depending on the texture and therefore function given to the surface. For example, it can be used to optimize air flow, control bacterial growth, provide super-hydrophobicity/hydrophilicity, self-cleaning, light diffraction, etc. By varying the parameters (power, pulse duration, wavelength) and shaping the light, it is possible to structure the material in the desired way. Surface structuring thus offers a range of promising applications, which are constantly expanding thanks to advances in micro- and nanostructured surface fabrication and characterization techniques.

However, it's a process that's currently under development and needs to be optimized before it can be used at large scale in the industry. Yield and precision are challenges that beam-shaping can solve. To increase yield, several solutions can be employed, such as augmenting the power and scanning speed, along with implementing parallel processing techniques. Additionally, optimizing the shape of the beam can significantly contribute to higher yield rates enabling to have a large beam onto the surface with an energy density just at the ablation threshold over the whole beam (in the contrary of a Gaussian beam with which an energy density peak in the centre is unavoidable) even at high power. On the other hand, to enhance precision increasing the Numerical Aperture and utilizing diffraction-free beams might be considered. Shaping the beam optimally and reducing the wavelength can also lead to improved precision, enabling more accurate and reliable outcomes in diverse fields of application. Beam shaping plays a crucial role in addressing the challenges of yield and precision in various applications.

2. Solution provides by MPLC technology.

2.1. Multi-Plane Light Conversion

Multi-Plane Light Conversion (MPLC) is a technique that allows performing any unitary spatial transform. Theoretically, it enables the lossless conversion of any set of N orthogonal spatial modes into any other set of N orthogonal modes through a succession of transverse phase profiles separated by free-space propagation serving as a fractional Fourier transform operation. The principle of the MPLC is shown schematically in Figure 1.

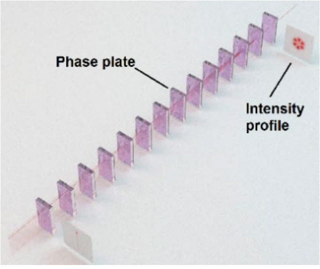

Fig. 1. Principle of MPLC

MPLC has been historically implemented using a multi-pass cavity, in which the successive phase profiles are all manufactured on a single reflective phase plate (see Figure 2). The cavity is formed by a mirror and the reflective phase plate with the light going back and forward both surfaces.

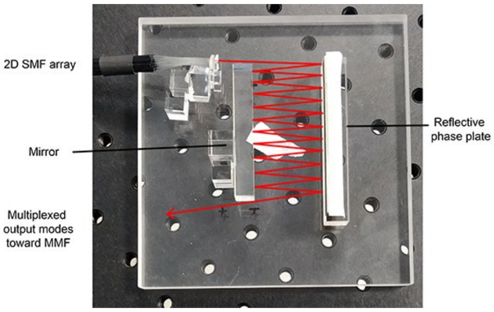

Fig. 2. Picture of a MPLC with fibered inputs. The beam path is shown in red.

MPLC technology enables complex beam shapes with a high control over amplitude and phase. The free-space reflective design allows for high beam shaping quality whilst conserving the property of the laser, such as the depth of field, which is not usually achievable through other beam shaping methods. Moreover, MPLC technology may be adapted to a wide range of wavelengths from visible to IR. Therefore, MPLC technology is well adapted to laser processing.

2.2. Integration system

In this paper we analyse an experiment based on a typical of the industry set-up and equipment. The assembly consists of a Light Conversion Pharos (green) laser with a wavelength of 515nm. It sends between 250-1000fs pulses at 3W power into a beam expander and then into the beam shaping module. The beam shaping module based on patented Multi-Plane Light Conversion (MPLC) technology. Fully reflective, the module is designed to withstand high-energy femtosecond laser pulses with remarkable stability. A 14mm aperture galvo-scanner and two different F-Theta lenses, depending on the size of the beam on the processing plane, complete the set-up. The aim is to generate conformal LIPPS rapidly on stainless steel.

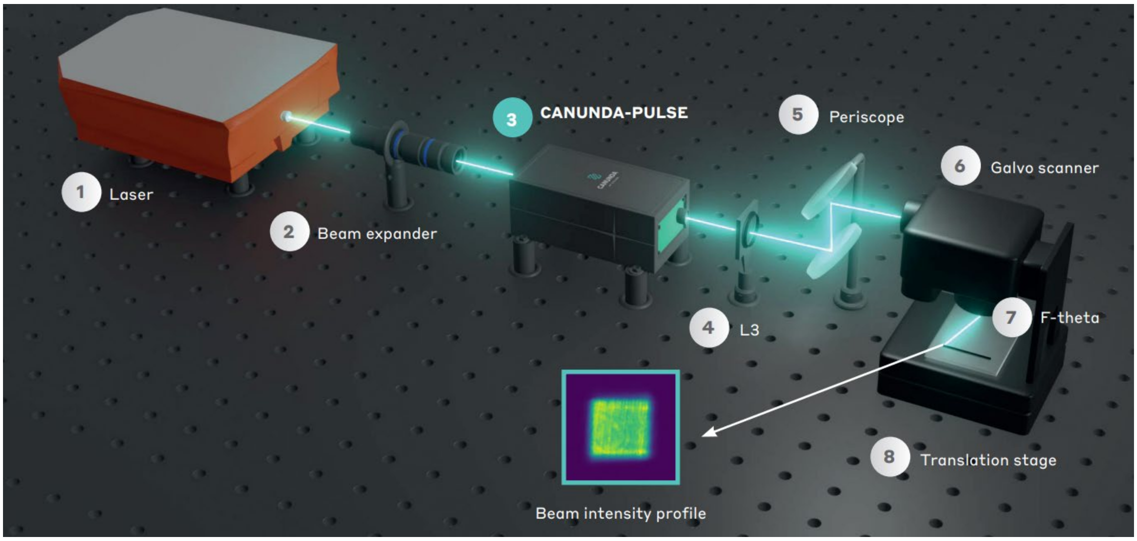

Fig. 3. Integration system

3. Results obtained with IFSW

3.1. Finding the optimal shape

To determine the best relevance, two different sizes of the square top-hat have been tested and compared. After parameter optimization, tests of the two different square sizes were carried out on stainless steel at 1kHz and 40 pulses per spot.

The first configuration is a 130µm square top-hat (see figure 4 and 5), generated by a 260mm F-Theta lens. The fluence is 0.12j/cm².

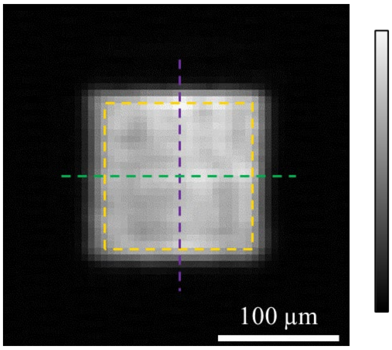

Fig. 4. 130 µm top-hat in the treatment plan

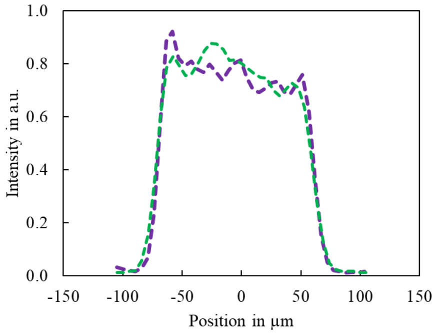

Fig. 5. 130 µm beam profile

The second configuration is a 50µm square top-hat (see figure 6 and 7), generated by a 100mm F-Theta lens. The fluence is 0.16j/cm².

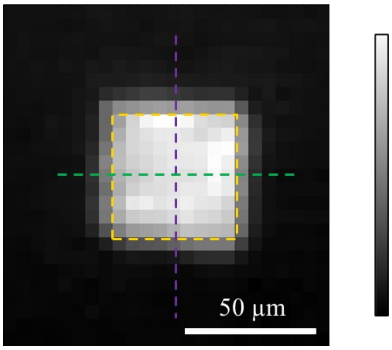

Fig. 6. 50 µm top-hat in the treatment plan

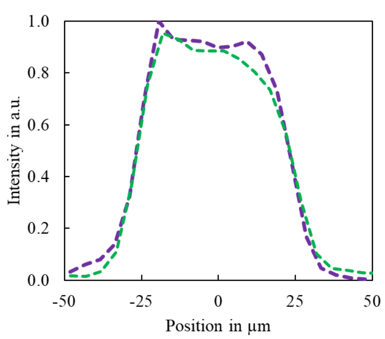

Fig. 7. 50 µm beam profile

In both cases, LIPPS were generated uniformly. A scanning electron microscope (SEM) clearly distinguishes textured from non-textured surfaces. However, the transition between textured and non-textured surfaces is clearer when using a 50µm square top-hat.

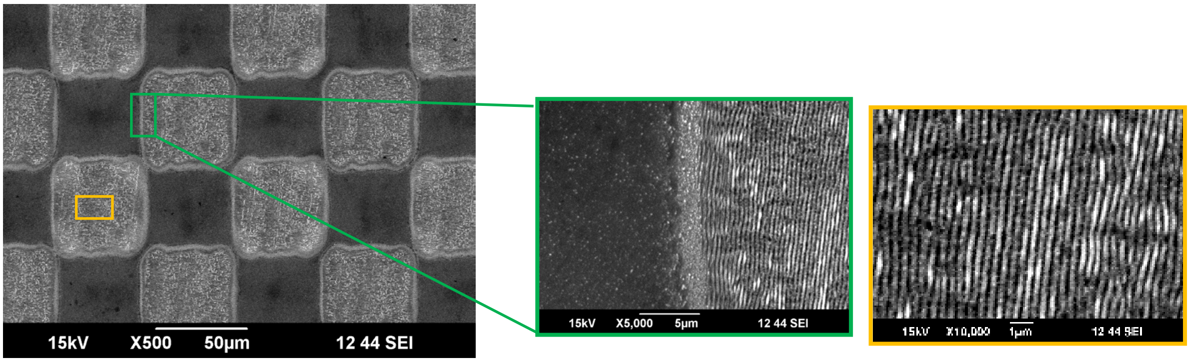

Fig. 8. SEM Images of the 50 µm square top-hat

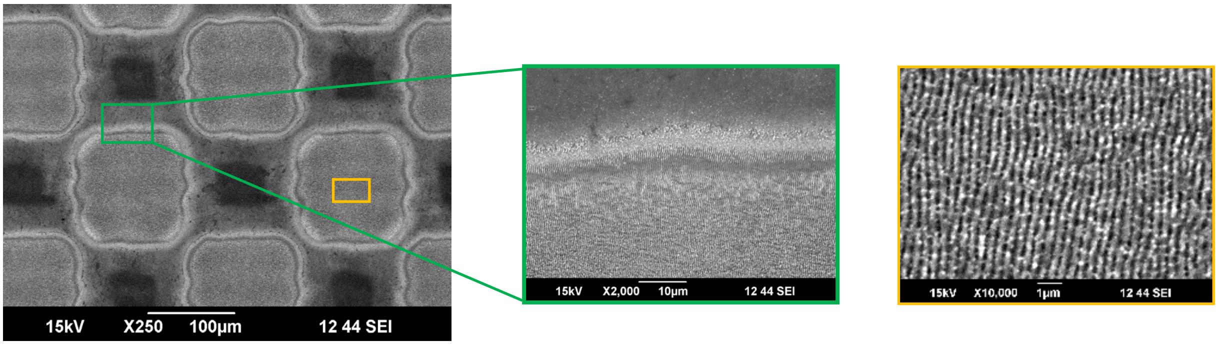

Fig. 9. SEM Images of the 50 µm square top-hat

3.1. Comparison between 515nm and 1030 nm lasers

To demonstrate the benefits of using a 515nm green laser to generate LIPPS, we compared the results with those obtained using a 1030nm infrared (IR) laser in the same industrial configurations. We found that que in line with theory, the use of a green laser makes it possible to halve the LIPPS period. Compatibility with this laser is also a gateway to the shaping of other types of lasers for future applications.

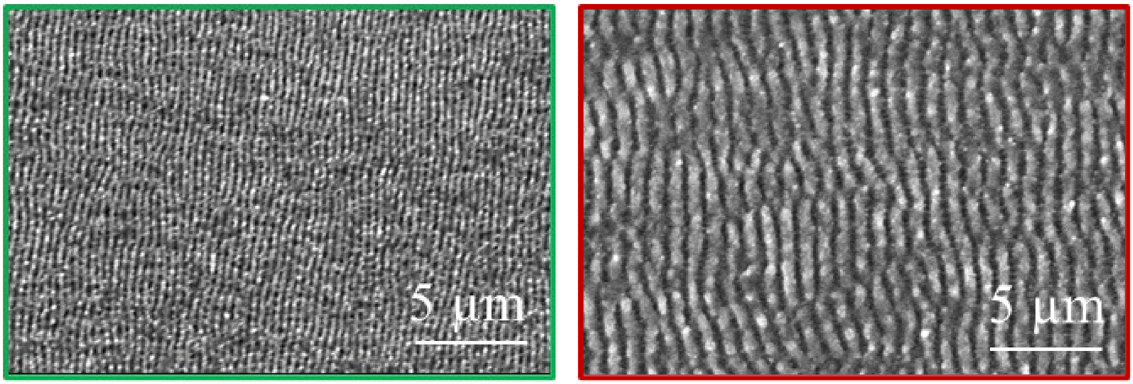

Fig. 10. SEM images of textured sample using green laser (left) VS IR Laser

4. Conclusion

Cailabs and IFSW have successfully showcased surface texturing, where they utilized a green square top-hat beam to generate Laser-Induced Periodic Surface Structures (LIPSS) on stainless steel. This innovative approach resulted in sharp-edged patterns with a consistent and uniform profile across the Field of View (FOV) of the F-theta lens. Notably, the achieved structures were smaller in size compared to those obtained using Infrared (IR) texturing techniques. The results have sparked a series of ongoing developments, with plans to conduct tests using various beam-shaping systems, including the top-hat shaper, Bessel beam, and beam splitting methods. Moreover, they are exploring the potential of different wavelengths and higher power levels to further expand the scope and applications of this surface texturing technology in the coming months. These advancements hold promising prospects for diverse industries and applications where precision and yield are paramount.

References

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